ArcheoKM: Toward a Better Archaeological Spatial Datasets Management

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Abstract.

Most of knowledge management research done on excavated objects is based on non-spatial data. Semantics is used both to focus on data integration among heterogeneous datasets and to build up a common language in order to develop a common framework. Consequently, data is self-describing and allows generic and automatic processes. The lack of semantic data that describes objects spatially is an issue that we address. Actually, our proposition is based on a web platform which uses semantic Web technologies and knowledge management processes. Our proposition focuses on the identification process which consists in managing data generated during the excavation process. The spatial data are linked to knowledge bases acquired during the identification process. By annotating data with semantic definitions, our Web platform provides a semantic view on spatial data sets. One of the highlights of the system is the involvement of the archaeologists in order to define the management rules. These rules are used to set up the components in the domain ontology which define the knowledge. The knowledge generated and managed through management rules and semantic indexations is used to provide the user with semantic Wikipedia pages. The paper also demonstrates how the spatial analysis on the spatial dataset could provide an extra dimension to the knowledge generation and its management.

Keywords: Industrial archaeology, knowledge management, information system, ontology, spatial data

1.0 Introduction

Geometry has always been the dominant component in any system related to an archaeological project. The objects extracted through the excavation sites process are highlighted by their geometries. The geometry is a dominant factor in any archaeological projects. This fact has prompted to think that a system related to such projects is either 3D object modeling systems or Geographic Information Systems (GIS). Actually, they rely heavily on object geometries and their relations with the surroundings. In the whole process the semantics of the geometric objects and their relationships with the surroundings are neglected.

With the advancement of survey technologies, data could be collected more accurately. In one hand, this has provided a great advantage in analysis process as we have more and diverse data to perform the precise analysis. In another hand, it has created difficulties in managing them with existing database systems. This fact is due to their size and diversity. This issue is even more visible in an industrial archaeological project. Indeed, the sites of excavation are available for very limited time and thus the data should be collected and stored in very short time. In addition, the diversity of data makes complex the management of information with the existing database systems. Hence, there is lots of research going on the field of data indexation and information retrieval in order to reach the level where this vast amount of information could be managed through the knowledge defined by the archaeologists. Actually, the knowledge about the objects excavated from the sites could only be defined by the archaeologists.

We propose a method which is a blend of adjustment the old methods and take advantage of the emerging cutting edge technology. The system still proposes to retain the storing mechanism with the existing database management systems and consider geometry as one of the major data types. Moving on, we suggest use of a collaborative web platform based on semantic web technologies and knowledge management to handle the information by several archaeologists and technicians. The platform will be able to store data during the excavation and manage them through the knowledge acquired during the identification process. Furthermore, it facilitates the collaborative process between the archaeologists to generate knowledge from the data sets. The main principle of our approach is to use semantic annotation to provide a semantic view on data sets. The shared ontology that defines an index on the semantic annotations allows us to build a global schema between data sources. This global schema allows us to annotate, index, search and retrieve data and documents.

Section 2 highlights the research works that have been carried out in the past and the work that are currently undergoing. Section 3 focuses on our system. The section gives details about the data type with which we are working. Additionally, it draws the scenario of the case study. In addition, the section describes the architecture of our system. Finally, section 4 concludes the paper.

2.0 Background

Conventionally, an Information System for archaeologists is a Geographic Information System or a 3D object modeling system. The statement has been supported by the current commercial applications for the archaeologists. Applications like ArchaeoCAD from ArcTron (http://www.arctron.com) and PointCloud from Kubit (http://www.kubit.de) rely heavily on the geometry of the objects excavated. The applications are thus used primarily to represent objects excavated in a 3D space. Similarly, GIS vendors like ESRI (http://www.esri.com) uses the spatial information of the objects to analyze them spatially. Meanwhile, the data collection process has seen a tremendous change in the last few years. Today, it is not only the amount of data that needs consideration, the diversity of data should also be taken into account. It is becoming increasingly difficult to manage them solely with the current database system due to the size and diversity of the data. In addition, information systems in Archaeological projects or Cultural Heritage projects is lacking from a complete package. There have been lots of researches going on but they are on the independent components. However, research projects like 3D MURALE [1] and GIS DILAS [2] contains most of the elements needed for a complete package and hence could be considered as comprehensive Information System. 3D MURALE system is composed of a recording component, a reconstruction component, a visualization component and database components. The findings are managed through a database management system. Once the findings are stored in the database with a proper data structure, the objects are reconstructed through the reconstruction component. This is done by modeling the objects in 3D space. These 3D models are displayed in the visualization component. DILAS is a generic, fully object oriented model for 3D geo-objects. The 3D geometry model is based on a topologically boundary representation and supports most basic geometry types. It also incorporates the concept of multiple levels of detail (LOD) [3] as well as texture information. It is clear that the existing systems rely heavily on the geometries of excavated objects for their representations, but interoperability of systems and knowledge sharing remains a gap.

The sharing of knowledge in archaeology and disseminate it to the general public through wiki has been discussed in [4]. Likewise the use of knowledge to build up a common semantic framework has been discussed in [5]. Research works exist in the field of archaeology, but most of the research is carried out in other related fields. However, it could be applied in archaeology as well. The existing researches focus more on using the common language for efficient interoperability. The research project [6] concerns the achieving syntactic and semantic interoperability through ontologies and the RDF framework to build a common standard. Data integration through ontologies and their relationships is discussed in [7]. Although the work on semantic web and knowledge management in the field of Information System in Archaeology or related fields is stepping up with these research works, despite the fact that they are in very preliminary phases. Additionally, these projects concentrate more on how to achieve interoperability with semantic frameworks and ontologies. However, no one focuses on the knowledge generation process and more specifically on rules defined by archaeologists in order to build up the system which should use, evaluate and represent the knowledge of the archaeologists [4, 5, 6, 7].

3.0 Principle of the Web platform ArcheoKM

ArcheoKM plans to complement the principle of Knowledge base where it can be used by archaeologists to develop knowledge rules from the data excavated. The knowledge stored in machine readable format then is translated into human readable format. Moreover, it moves beyond managing the concepts defined to annotate documents (which most of the research projects currently focusing on), to the instances of concepts with their own property values. In this manner, an object found in a point cloud can be linked, with the help of an instance in the ontology to other documents (a part in an image or a section of archive document) that contains the same object. The second aim of the ArcheoKM is to give archaeologists the possibility to manage Wikipedia pages on findings. These Wikipedia pages represent the knowledge formalized by archaeologists and are managed through a 3D scene where 3D objects are linked to Wikipedia pages. In a way the representation of knowledge in Wiki pages shows the transformation of machine readable knowledge base to human readable knowledge base.

This section discusses about our approach of using semantic web and knowledge management in the field of Archaeology and how they could be used efficiently to handle large multimedia data sets taking Industrial Archaeological Sites (IAS) as the case study. It also contains brief introduction about Knowledge Management. Additionally, the section also tries to provide a glimpse of the data pattern and how they are collected.

3.1 Knowledge Management

Knowledge contained in documents has been traditionally managed through the use of etadata. Before going on details about knowledge management, let us first understand the perspective about the whole idea. Every activity begins with data. However data is meaningless until they are put in context of space or an event. Additionally, unless the relationship between different pieces of data is defined, simply data do not have any significance. Once the data are defined in terms of space or events and are defined through relationships, they become Information. Information are very important to understand the nature of the data but they do not provide the reasons behind the existence of data and are relatively static and linear by nature. Information is a relationship between data and, quite simply, is what it is, with great dependence on context for its meaning and with little implication for the future [8]. Beyond every relationship, there arises a pattern which has capacity to embody completeness and consistency of the relations to an extent of creating its own context [9]. Such patterns represent knowledge on the information and consequently on data.

The term Knowledge Management has wide implications. However, very precisely Knowledge Management is about the capture and reuse of knowledge at different knowledge level. In order to access the knowledge, data are annotated and indexed in the knowledge base. This is in lined with the concept proposed by Web Semantic where it proposes to annotate the document content using semantic information from domain ontologies [10].

The goal is to create annotations with well defined semantics so they can be interpreted efficiently. Today, in the context of Semantic Web, the contents of a document can be described and annotated using RDF [11] and OWL [12]. The result is a set of Web documents interpretable by machine with the help of mark-ups. With such Semantic Web annotation, the efficiency of information retrieval is enhanced and the interoperability is improved. Information retrieval is improved by the ability to perform searches, which exploit the ontology in order to make inferences about data from heterogeneous resources [13].

3.2 Data Collection and Patterns

Industrial Archaeology is perhaps best suited field in archaeology to carry out our research as Industrial Archaeological Sites (IAS) are available for very short duration of time.

It makes time availability very short to store them which is one of the concerns we want to address here. Additionally, the amount of data that is collected in this short span is very large and diverse. ArcheoKM uses the site of Krupp factory in Essen, Germany. The 200 hectares area was used for steel production during early 19th century and was destroyed in Second World War. Most of the area has never been rebuilt and thus provides an ideal site for industrial archaeological excavation. The area will be used as a park of the ThyssenKrupp main building in 2010. Actually, we are running out of time to collect data. The first challenge consists in creating a relevant data structure which helps in retrieving those data efficiently. In addition, the data which have to be collected are huge so the system should be able to handle a huge data set.

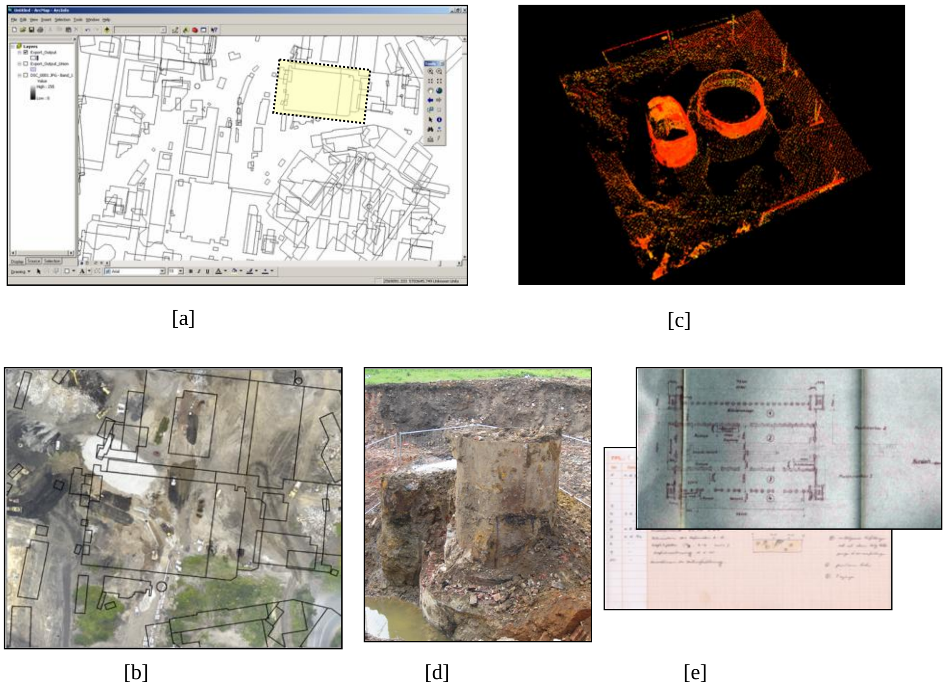

Fig 1: Heterogeneity nature of data [a] Site Plan layed out as GIS data in ArcGIS *(highlighted the area of Oven)* [b] Orthophoto from aerial image overlayed with the Site Plan *(Oven area).* [c] Point Cloud of Oven [d] Image of the Oven. [e] *(top)* Floor Plan *(down)* Archaeological notes

The nature of the dataset generated during the project is heterogeneous. It could be seen in figure 1. As could be seen, the acquired data ranges from scanned point cloud from terrestrial laser scanners to the floor plans of old archive. The primary source of geometric information is provided through the point cloud. The point clouds have resolutions of 0.036 degree and are in Gauss Krüger coordinate system, zone II (GK II). It is the main data set used for the 3D object modeling. Beside point clouds, huge amount of images are also collected during the excavation. Most of the images are taken with non calibrated digital camera so do not contain any information about the referencing system. Even though they do not contain any referencing information they posses vital semantic information and could be used for the formulation of knowledge. However, there were photogrammetric flights to acquire aerial images of the area. The aerial images were processed to generate a digital orthophoto with a resolution of 10 cm. The digital orthophoto is again in Gauss Krüger referencing system (GK II). To add on this, huge archive data have been collected. Those data contains floor plans, old pictures and other semantic information. Likewise, the notes taken by archaeologists are also important to acquire semantic information of the findings. ArcGIS databases are also available depending on the site and its nature. These databases are in the GK II reference system. For our example, this database gives an overview of the site and can be overalyed with the orthophoto in order to identify the interesting locations easily as can be seen in figure 1 (b).

3.3 Case study scenario

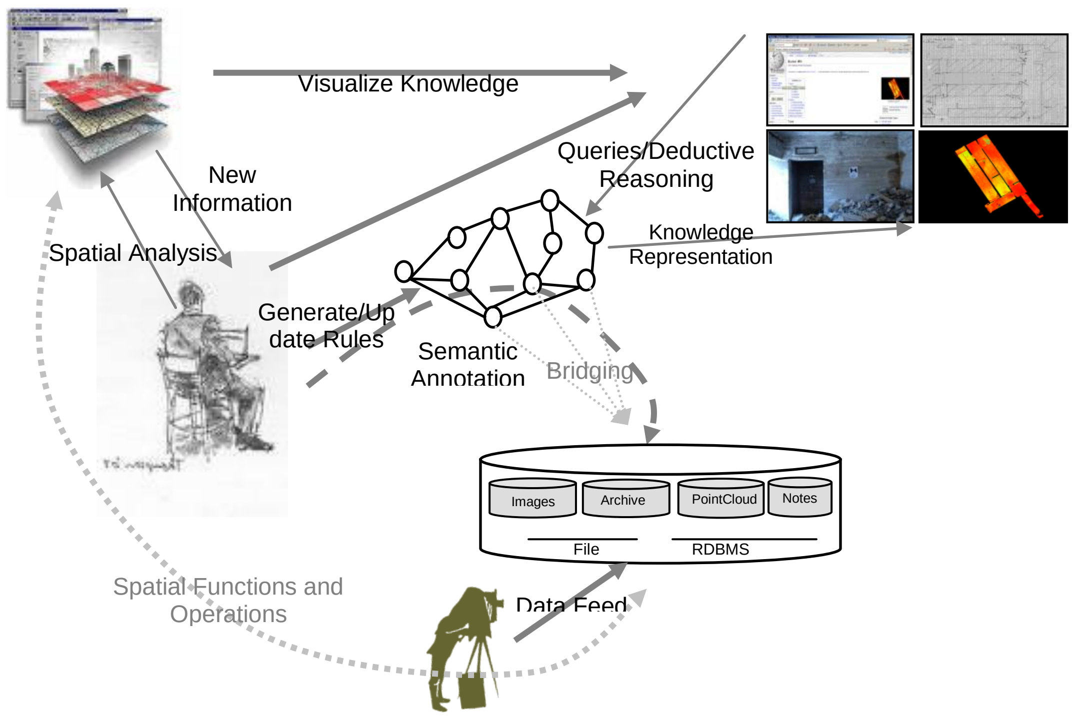

Fig 2: Case study scenario of the concept

The figure 2 describes the behavior of the system displaying how the overall system functions to generate knowledge from the data excavated. The information are collected from the excavation site and most of them are stored in their native format. However, the Point Cloud and the archaeological notes are converted and stored in the Relational Database Management System. The Point Cloud and other spatial information are stored as spatial data type in the database system where as the archaeological notes are stored as attributive data type. Other data like the images and archive are stored as file system. Since, the data are collected in very short time; it is very difficult to design a comprehensive storing structure of the repository. Nevertheless, it is necessary to consider the storing structure of the repository and the services that will be available to store and search on the various data sets. The simplest approach would be to index the objects in the 2D map (in our case the Orthophoto) through the bounding boxes first and then relate the data and document to them. This could be done through the semantic annotations of the data and documents to the objects indexed in the Orthophoto. It brings two immediate benefits – a) it provides a platform where all the datasets are linked through a common referencing system and thus becomes easier to extract information b) it provides the identifications of the objects excavated.

Archaeologists are involved to derive the relationships among different objects and their surrounding. This is very important to draws the scenario of the site and to provide an initial semantic model. Later these relationships will be modified through different processes to finalize the complete model. We term these relationships as “Domain Rules (DRs)”. Those DRs are the backbone of the system as they will enrich the knowledge base and setup domain ontology for the system. In this way, the domain ontology and the instances of the ontology classes will be defined by DRs defined by the archaeologists. To explain it more with an example, we would like to draw a hypothetical scenario of an excavation site where a bunker used to store raw material and with three rooms has been excavated. Archaeologists can formulate DRs of the excavated bunker as "*Bunker has Rooms*" and "*Bunker name is RawMaterialBunker*". With these two DRs, initial domain ontology could be designed as they consist entities and relationships needed for the domain ontology: *Bunker* and *Room* could be classes which are related with *hasRoom* relationship. Similarly, the Bunker has an instant *RawMaterialBunker*. The ontology could be extended with the instances of rooms in the bunker. Thus those two DRs are used to formulate a section of domain ontology which is shown in the figure 2 a.

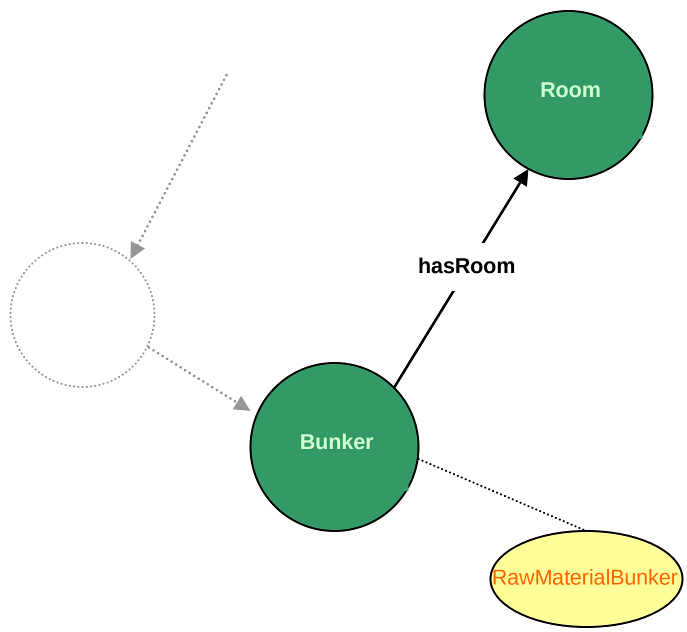

Fig 2 a: A section of domain ontology formulated by two DRs: Bunker has Rooms and Bunker name is RawMaterialBunker

In addition to defining the rules archaeologists can identify common archaeological findings to create knowledge through semantic annotations. It is very important to involve archaeologists in this step as they are the best person to identify the findings. The semantic annotations of the geometries of the objects are done through the Minimum Bounding Rectangles (MBRs) in the Point Cloud where as that of images and the archive data are done through the URIs of the files. Similarly, the data in RDBMS like the archaeological note entry is annotated through browsing the relevant data in the database itself. As mentioned, the annotated data and documents are then indexed to the relevant entities within the domain ontology.

The knowledge generated through the semantic annotation and referencing to the semantic objects in the ontology should be represented in more user readable format. It will be achieve through user interfaces comprising different web pages to represent different category of knowledge. This could be taken as the face of the system where use will interact with the information obtained during excavation and underlying knowledge in them. The most prevailing representation platform will be semantic Wiki where the knowledge generated through the semantic annotation and managed through the DR and domain ontology will be represented in human readable formats. The system will use the deductive reasoning capacity of OWL-DL [14] to interpret hidden knowledge and represent them in the wiki pages. Moreover, other representations like the 3D object model and GIS representations of the objects will be carried out through various emerging technologies with the web environment. The spatial analysis on the data (especially with the Point Cloud and GIS data) provides the system the much needed reality check on the ontology. Additionally, the spatial operations and functions on the data will generate new information that could be stored in the database and can provide new knowledge through new rules which could be applied in the domain ontology.

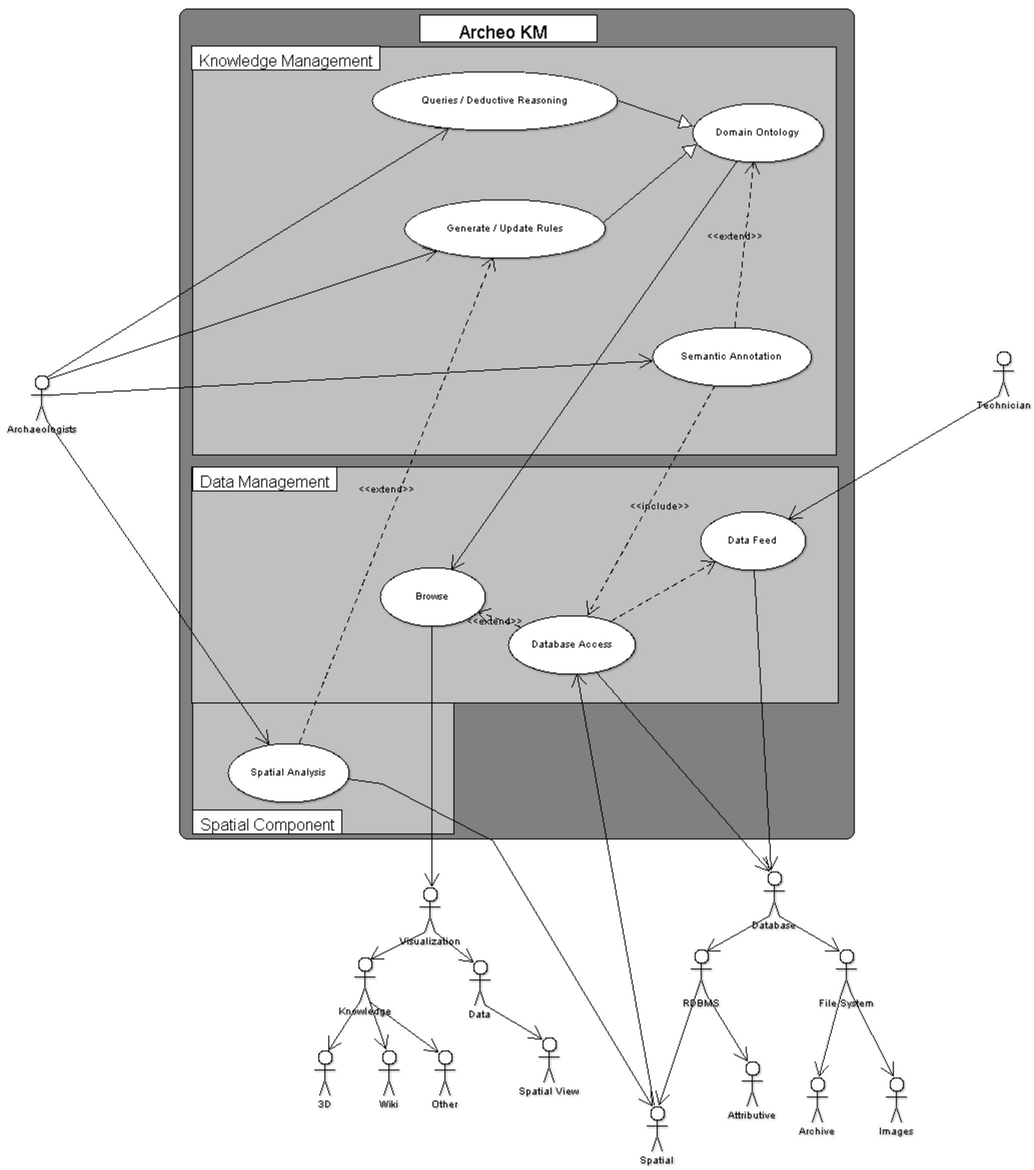

Fig 2 b: Process Diagram

The complete process could be seen in the figure 2 b. It describes the process of the behavior of ArcheoKM which has been discussed above. The data are collected from the excavation sites and are stored in RDBMS and File System. Archaeologists are the main player within the process and are responsibe to generate the domain rules (DRs) about their findings which forms base for the domain ontology. As already mentioned the entities in the domain ontology are derived through these DRs. Archaeologists are again involved to annotate the findings which provide their identifications in the data and the documents. These semantic annotations are indexed to the entities of the domain ontology to define the knowledge base. The domain ontology could be queried to derive required knowledge which is then represented through different web based mediums. In addition the domain ontology which is built with OWL-DL provides archaeologists the deductive reasoning possibilities to derive new and otherwise hidden knowledge in the domain ontology which is again portrayed through the web based mediums.

Spatial Analysis is an important step in the process diagram. Again it is the responsibility of archaeologists to perform spatial operations in the spatial data to have reality checks in their DRs. The spatial analysis provides functions beyond reality check. As could be seen in the figure new data can be generated through these operations and can provide new DRs which in turn could provide additional input to the domain ontology. These new data are stored again as the spatial data in the RDBMS. These new entities need to be indexed against the new data which is again provided through the semantic annotations on the spatial data.

3.4 System Architecture

ArcheoKM is a web based system and functions under three major levels. Each level has its own distinct functionality and is interdependent to each other. Figure 3.0 shows the system architecture of the system.
The bottom level is the Syntactic level. This level has all the information excavated from the site stored. As discussed earlier, they are either stored in the file formats like images or archive data or stored in the Relational Database Management System like archaeological notes or scanned/GIS data. Today, almost all the database systems have incorporated Spatial Extension included and this has made the storage and retrieval of geometric data very convenient. Additionally, they provide spatial operations and functions which allow us to analyze the geometric data spatially. The geometric information acquired through the terrestrial laser scanners is stored in the database system as spatial data types. Basically, these geometric data are the set of point clouds with 3 dimensional coordinates. They are the major data in context of the ArcheoKM as they provide visual representations of the findings during excavation. With the help of spatial operations we can derive the bounding boxes of the object during the storing or after during the retrieval of these data. Additionally, the site plan of the area which is digitized and stored as "shp" files in ArcGIS will also be stored in the RDBMS. With the advancement in database technology, today it is possible to store the point cloud as Binary Large Object (BLOB) data type as in Oracle 11g with spatial extension [15] or Extended Well Known Text [EWKT] as in PostGIS 1.3, the spatial extension of PostgreSQL 8.3 [16]. The ArcGIS data can be exported to the above mentioned database system either through the tools developed by ESRI or tool within the database systems themselves. An example of such tools will be the loader (shp2pgsql) and dumper (pgsql2shp) tools within PostGIS which allow converting "shp" file to spatial data of

PostgreSQL and vice versa. The ArcheoKM intends to use PostgreSQL to store its data because of its flexibility and cost efficiency over other database systems.

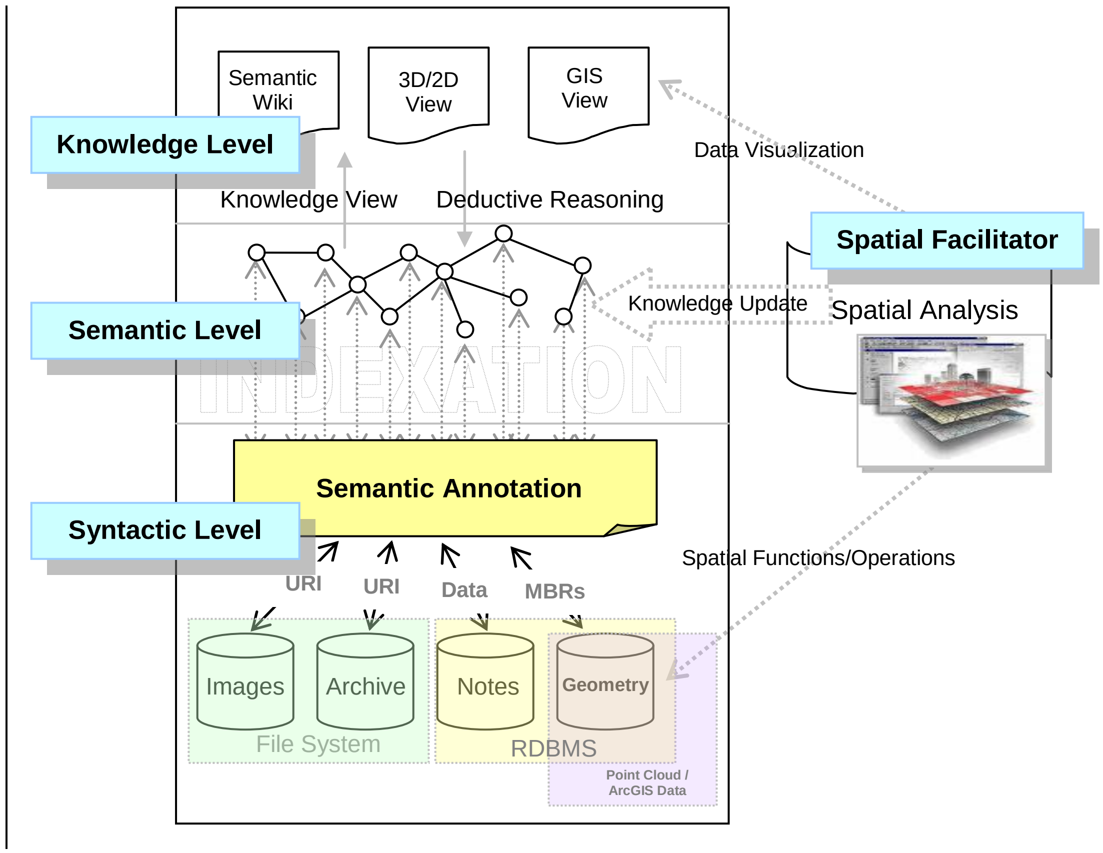

Fig 3: System Architecture of KM-Archeo

One of the major functionalities within the syntactic level is to define annotations on data. The data needs to be annotated against the objects indexed in the Orthophoto for the proper identification. Through annotating the data semantically, knowledge is generated. As could be seen in the figure 3, the annotations are done through different methods according to the data pattern but basically they are done through three distinct methods: Minimum Bounding Rectangles (MBRs) for the Point Cloud, Uniform Resource Identifier (URI) to images and the set of data to the Archaeological notes. All those annotations are done through RDF technology. The technology also allows linking these annotations to the components of ontology in the semantic level.

The next level is the semantic level. Through this level the knowledge generated is managed. It is achieved through the ontological structure setup through the rules defined by the archaeologists. Within this level the domain ontology evolves through each valid rules defined. Archaeologists are involved actively in this phase as they are the one best suited to provide entities and their relationships needed to build up the domain ontology. In order to maintain a common standard among the archaeologists to define the terms used in the ontology, existing standards like standards from CIDOC or other Archaeological standards will be used and extended. However, it should be understood that defining a new standards for archaeology or modifying existing standards are beyond the scope of this project.

The semantic annotations from the Syntactic level will be indexed semantically to the entities of the domain ontology in this level. This semantic index is the building block of the domain ontology and through semantic annotations provides semantic view of the data. It also provides global schema between various data source making the data integration possible at certain level. This level represents a bridge between interpretative semantics in which users interpret terms and operational semantics in which computers handle symbols [17].

The top most is the most concrete one which represents the organization of the knowledge on the semantic map. This level provides the user interface in form of web pages to display the knowledge generated through semantic map. As could be seen in figure 3, this level has different web pages representing the knowledge. The pages are interrelated and could be navigated according to their relevance. The stand out representation of the knowledge is however through the semantic wiki [18]. These wiki pages are not only designed to show the knowledge that are generated and managed through the bottom two levels, they are designed to perform semantic queries to derive new knowledge. This will be possible through the interface within the semantic wiki – the semantic wiki will provide a platform through which user can launch their queries and the results will be displayed through the query languages of RDF like SPARQL [19] or SWRL [20]. In this way they will be different from the existing wiki pages. Thus, ArcheoKM is close to the semantic extension of Wikipedia [21], but data handling and managing extends beyond textual data. It also handles 3D or 2D object models of the findings besides the textual and image data. It will guide archeologist to define Wikipedia pages concerning subjects and objects of the site that represent knowledge. This level is called the knowledge level because it represents the specification of the knowledge of archeologists concerning the industrial findings.

Besides, the three levels the system architecture contains a component to facilitate the knowledge validation, upgrade and generation. As could be seen in the figure 3.0, it is Spatial Facilitator. This component is responsible for analyzing the spatial data spatially and provides the result either to update the current ontological structure in the semantic level or to create new spatial data. The newly created data themselves could be used to annotate semantically to generate new knowledge. In addition of creating new knowledge in the syntactic level, the spatial analysis on the data can create new entities in the domain ontology in which those semantically annotated data could indexed thus creating a whole set of new knowledge itself. An interface in the Knowledge Level will provide the visual representation of the analysis and could function closely with other components within the level. An example would be creating a buffer within certain feature in the site. This will generate a new set of data (data from buffering the feature) which will be stored in the syntactic level. This buffer could be annotated to generate new knowledge. Likewise, an entity (e.g. *bufferFeature*) will be added in the ontology in semantic level with relationship with other entities and the semantically annotated data (new data after creating the buffer) will be indexed to the entity so to manage the knowledge. In this way this component acts as a facilitator the knowledge handling.

4.0 Conclusion

It could be argued that the approach we have presented is a new approach in managing the semantic on spatial information through the use of semantic web and knowledge management. We are currently prototyping the system using JENA and PostgreSQL. The process works on computers in a local network. To implement the framework, we are using JENA (Semantic Web Framework for Java) [22] in order to build and to manage ontologies in JAVA. JENA helps us to handle an OWL database. We use the request language of JENA to retrieve data. Possibilities of integrating the reasoning capability of OWL DL (Web Ontology Language) to generate new knowledge through the existing one are being explored. We are in collaboration with archaeologists to generate knowledge through rules they define. A set of rule has already been defined and we are currently analyzing them to see how they could be translated into the domain ontology. Although, the case study uses industrial archaeology for describing the approach, it could be used in other areas where the spatial data are the predominant data type.

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